LIFE CYCLE ASSESSMENT OF POWER TRANSFORMER-CASE STUDY

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Abstract

This paper is a professional paper and it gives a short overview of legislation regarding environmental sustainability for power transformers. In the first part of the paper authors gives the definition and the review of Green Supply Chain Management and Life Cycle Assessment. The second part of the paper shows the case study of a LCA analysis for the power transformer.

Keywords: Life Cycle Assessment, Green Supply Chain Management, power transformers

1. INTRODUCTION

Nowadays, the increase in greenhouse gas (GHG) emissions in the atmosphere is currently one of the most serious environmental treats. Due to GHG emissions we will be witnesses of climate change which will cause damaging impacts in the next few decades [1]. These will primarily affect the natural and human systems [2]. At the same time these emissions are also a limiting factor for the economic growth of some countries, especially those in the transition process [3].

One of the reasons for that is the protocol, adopted in 2012 at Doha 2012 UN Climate Change Conference COP18 CMP8, at which the industrial world agreed to reduce the emissions of greenhouse gases approximately 18 % below 1990 levels by 2013–2020 [4]. In the meantime, also due to the climate change and the increase in environmental awareness all over the world, the concept of Green Supply Chain Management appeared. It is often defined as integrating environmental thinking into supply chain management [5]. So to define the emission of GHG for some product, Life Cycle Assessment (LCA) is needed to be carried out. LCA is a method which acts symbiotic together with GSCM initiatives.

An important example of green initiatives in the production of power transformers is recently published Regulation of the European Commission (EC) no. 548/2014 from 05/21/2014 in the implementation of Directive 2009/125 / EC of the European Parliament and the Commission as regards to the small, medium and large power transformers (Eco-Design Directive). The Regulation obliges all parties in the process of production or acquisition of new power transformers, and are located in the European Economic Areas to produce or buy transformers which are in accordance with the criteria set out in Regulation and Directive. Although that Directive applies for some time, it becomes mandatory to apply it from July 2015. The working group of the European Commission found that the introduction of the directive raised the level of efficiency transformers for approximately 20 % [6].

2. GREEN SUPPLY CHAIN MANAGEMENT

From the definition of Supply Chain management given by the Council of Supply Chain Management Professionals (CSCMP) [7], “Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities.” Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies.” Making it green, it could be simply illustrated as in Figure 1 and we can say that GSCM is a field of implementation of green thinking in all the segments of companies’ activities.

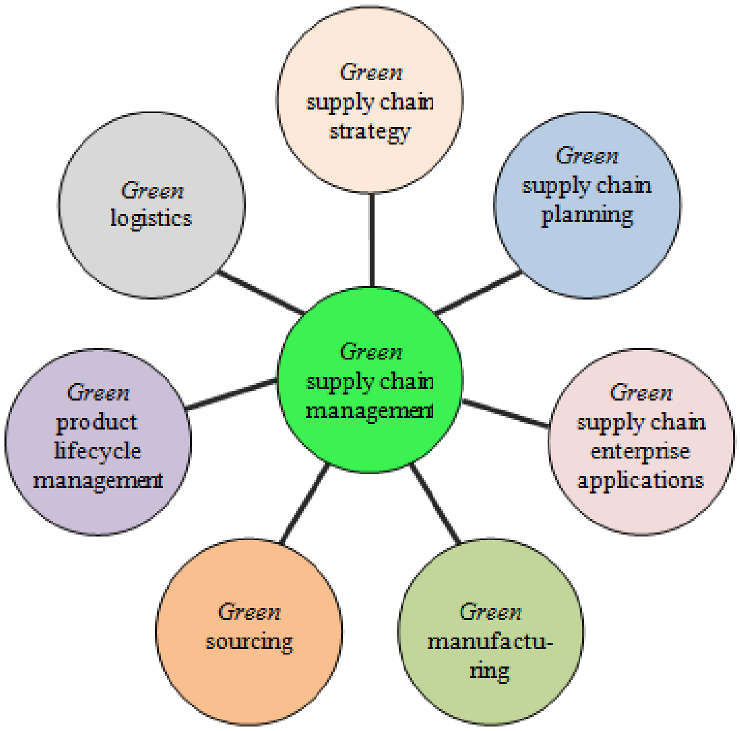

Figure 1 – Elements of GSCM [8]

Focusing on the definition of SCM and the three basic groups of activities - procurement, operations and logistics, green supply chain management could be illustrated as in Figure 2 [8].

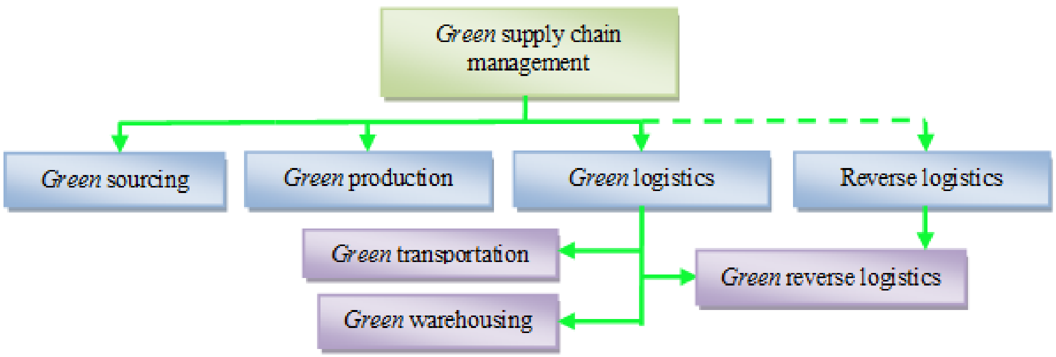

Figure 2 – Basic groups of GSCM [8]

3. LIFE CYCLE ASSESSMENT

The development of LCA methodology has its roots back in the late 1960's and early 1970's when the first studies applying a life cycle perspective on a process system took place in the USA, focusing on environmental impacts from different types of beverage containers [9].

In ISO 14040 LCA is defined as the "compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle". Thus, LCA is a tool for the analysis of the environmental burden of products at all stages in their life cycle - from the extraction of resources, through the production of materials, product parts and the product itself, and the use of the product to the management after it is discarded, either by reuse, recycling or final disposal (in effect, therefore, "from the cradle to the grave") [10]. Figure 3 presents LCA method.

According to ISO 14040 standards, LCA method has four 4 main phases [11]:

- the goal and scope definition phase,
- the inventory analysis phase.(Life Cycle Inventory-LCI),

- the impact assessment phase (Life Cycle Impact Assessment-LCIA),
- the interpretation phase.

Phase of the LCA methods and their mutual interaction are shown in Figure 4.

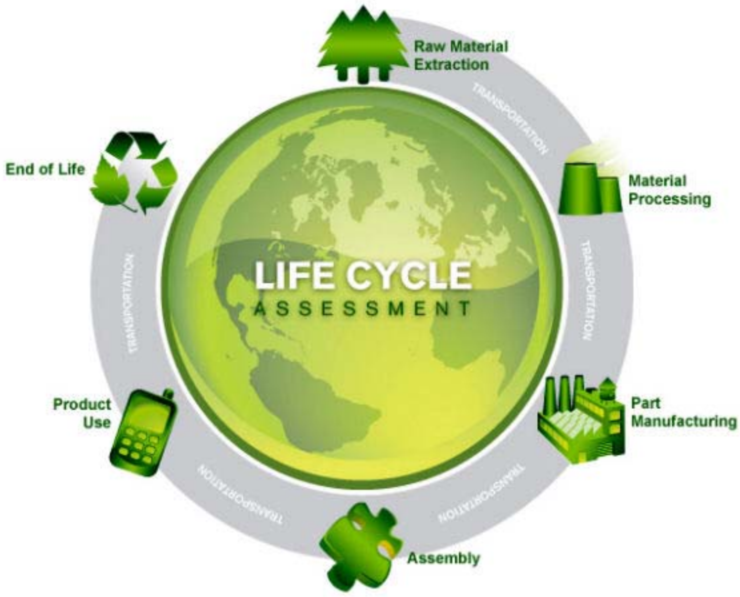

Figure 3 – LCA method

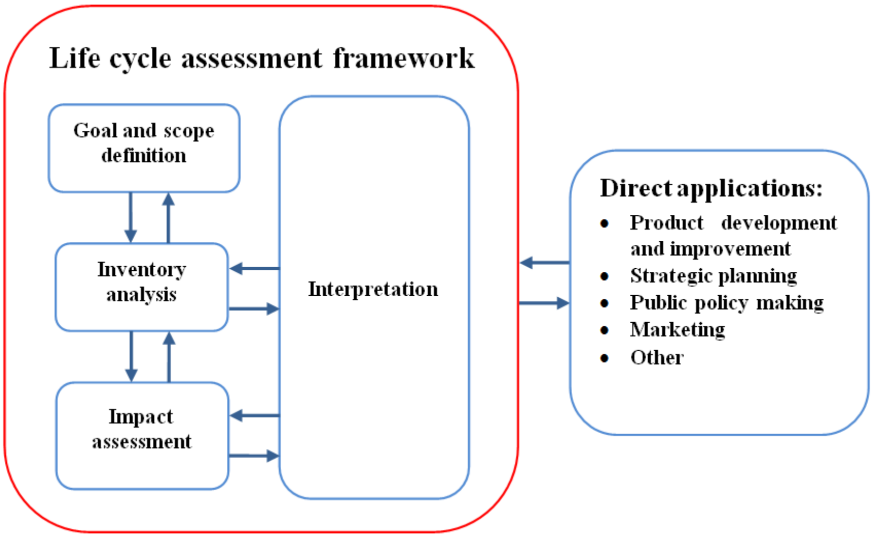

Figure 4 – LCA framework

In the first phase of the LCA method objectives, scope and amount of data to be used in the analysis are defined. This of course depends on the type of study. LCI phase of the method implies inventory of input/output data, which includes gathering needed data in order to fulfill the objectives of the analysis. LCIA phase is the phase of the LCA study which provides additional information, which helps to estimate the impact of production system on the environment (environmental significance). The last stage or stage of interpretation of LCA analysis is the stage where the results of phase LCI, LCIA, or LCA and LCIA are summarized and discussed in order to brought conclusions, assumption and decisions according with the purpose and scope of the analysis.

The ISO standard defines only the guidelines how to make LCA analysis. Because of this reason there are Product Category Rules and programs (SimaPro 7, EarthSmart, Open LCA, Umberto ect.) which standardize and facilitate the forming of the LCA analysis.

4. POWER TRANSFORMER

Transformers are effective devices for transformation of voltage and current. Their average efficiency is from 95 % up to 99.8 % [6, 12]. They are often the biggest, most difficult, most expensive and fundamental components of electrical networks, without which the efficient transfer of electrical energy in today's world is practically unthinkable. Because of very problematic standardization of materials, production process that requires a great deal of manual labor, they often have a high price. Representation of the transformer together with the position in the network is given in Figure 5 [6].

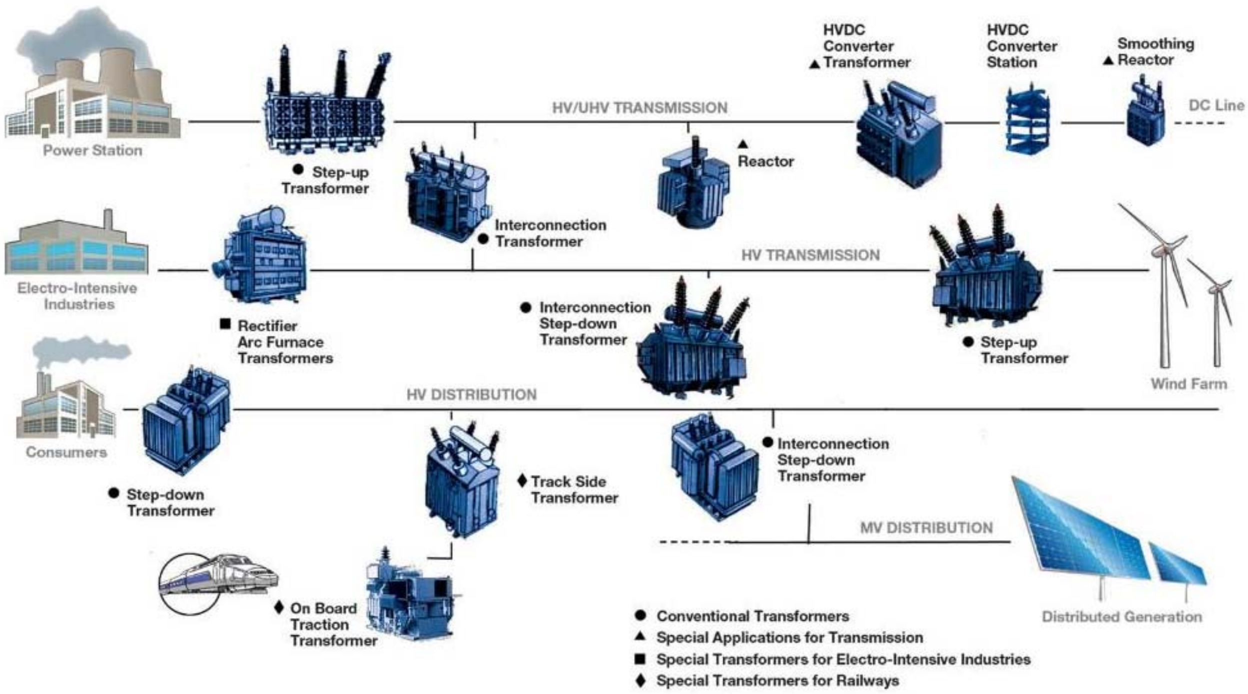

Figure 5 – Types of transformers and their position in the network [6]

Power transformer is a static construction with two or more windings. With the mechanism of electromagnetic induction they change the system of alternating voltage and current into another system of alternating current and voltage. The currents and voltages in principle remain at the same frequency. Large power transformers are used for lifting and lowering the voltage of electrical energy in order to achieve higher transfer efficiency. The main components of the power transformer along with a description of the basic functions, according to Figure 6 are:

1.) ferromagnetic core - magnetic flux guide,
2.) windings - conductors of electric current,
3.) connections - compound of winding and conductors,
4.) tank (filled with transformer oil) - transformer housing,
5.) bushings - connects the transformer to the upstream or downstream elements of the electrical energy network,
6.) cooling system - cooling of windings, core and metal parts due to losses in the same,
7.) switch - control of transformer transformation ratio,
8.) motor drive of the switch - drive of the switch.

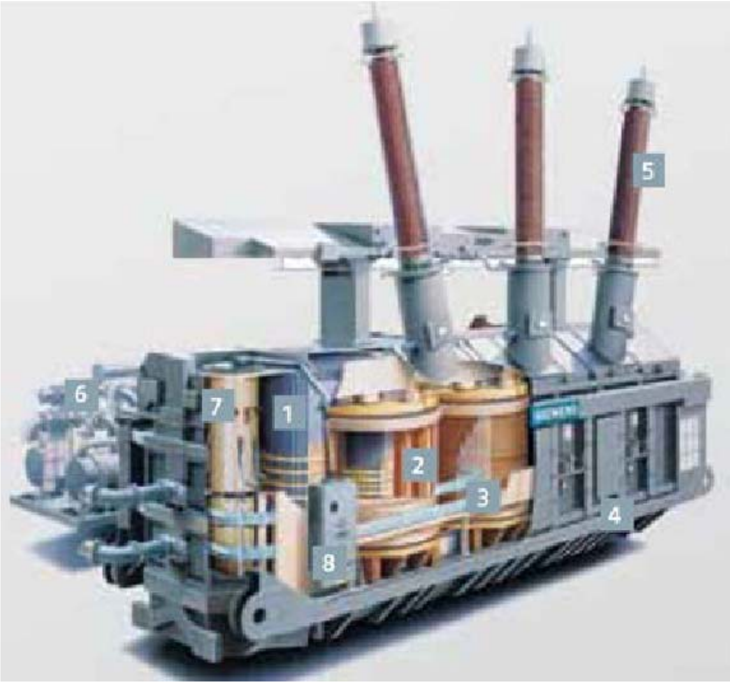

Figure 6 – Components of the power transformer

The life span of a typical power transformer is about 40 years. Taking into account the fact that the transformer is a strategic element in a network, without which the electrical energy supply is virtually impossible, they must be made very well. In the process of the production of the power transformer, producers try to predict the state that transformer could pass while in used. Therefore the intention is to ensure that the transformer is able to perform continuously in his life time period. The stages in the life of the transformer are shown in Figure 7 [13].

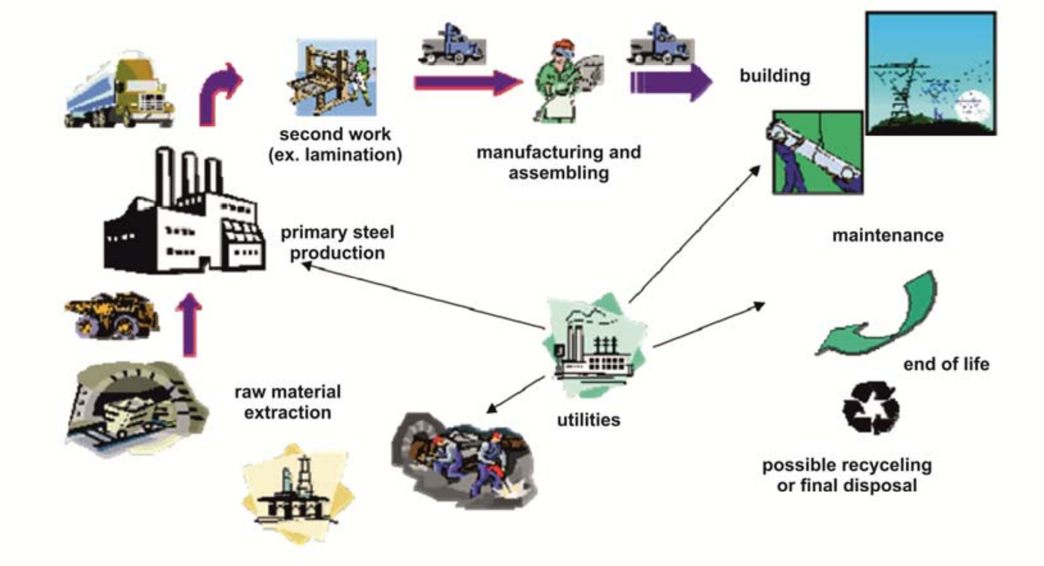

Figure 7 – The life cycle of the power transformer [13]

Figure 7 shows how the transformer goes through different life stages starting from the extraction of materials, production of individual components, production and assembly, transport, operation of the transformer and finally disposal or recycling of individual components, of course, where is possible.

5. LIFE CYCLE ASSESSMENT OF THE POWER TRANSFORMER

According to the LCA assessment framework, LCA consist out of 4 main phases. First phase is a definition of the goal and scope of the LCA. The goal of this LCA is to get quantitative information about the environmental impact of the power transformer through the whole life cycle. This LCA analysis is meant to be used only inside the company mainly for the optimization of the product development process. Functional unit is chosen to be one (1) Mega Volt Ampere (MVA) of transformer power.

A reference flow is represented by transformer of the nominal power of 210 MVA. Environmental impact of the transformer is analyzed with the life-span of 35 years. Impact of the infrastructure and equipment which is used for the production of this transformer is not taken into consideration in this LCA. Therefore this analysis is classified as type 2 analysis where life cycle of a product consists from three main phases: production of transformer which includes tri parts: material procurement, transformer manufacturing and transport to the customer. Three main phases together with the system boundaries are given on the Figure 8.

SimaPRO 7 software and Ecoinvent database were used to evaluate the environmental impacts. SimaPro is the most widely used LCA software that helps to collect, analyse and monitor the sustainability performance data of company's products and services. Furthermore IMPACT 2002+ impact assessment method was used which is in compliance with ISO 14044 standard.

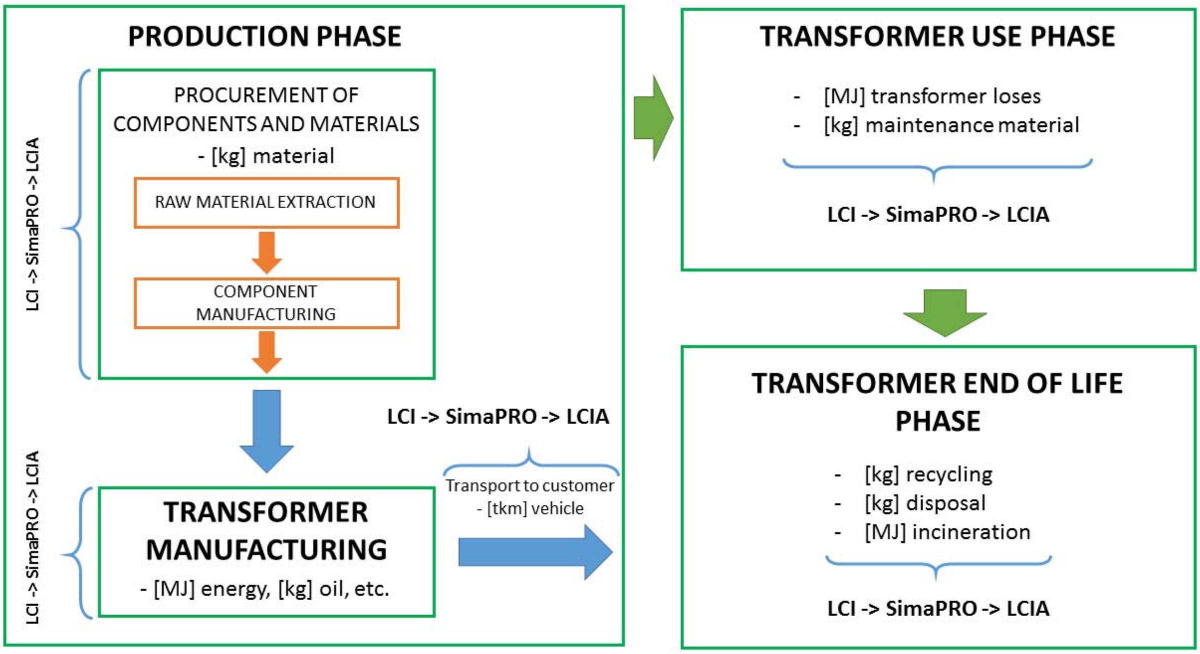

Figure 8 – System boundaries [6]

5.1. Production phase

Production represents one of the transformers life cycle phases. It consists of three main parts as it can be seen on the Figure 9. These parts are namely: procurement of components and material, transformer manufacturing and transport to customer. As shown on Figure 9, transformer consists of 4 main parts, active part of the transformers, metal part, transformer equipment and oil.

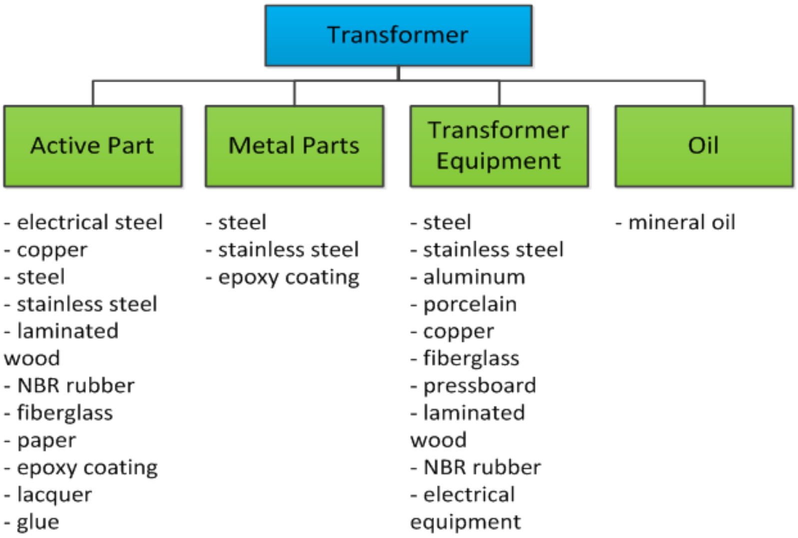

Figure 9 – Material used to build transformer [6]

To build the transformer, different types of material are used. The major material is electrical steel with more than 40 % of weight of the transformer. Second most used metal is steel. Cooper weights 16 % of the total weight. Big part of the transformer weight is oil, around 16 %. Press board and stainless steel weight only 1 % and 2 % respectively. There are other materials as well which contribute with less than 1 % to the total material weight. This is shown on Figure 10.

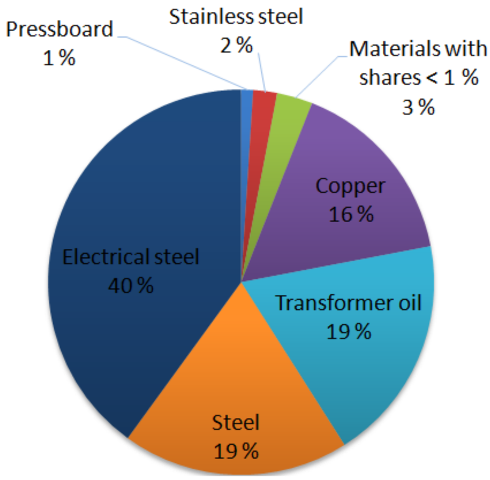

Figure 10 – Percentage of material used [6]

5.2. Transformer use phase

Transformer loses represent important part of the transformer use and they have to be taken in consideration in the calculation of the environmental impact. Percentage of loses in load and non-load working mode are show on Figure 11.

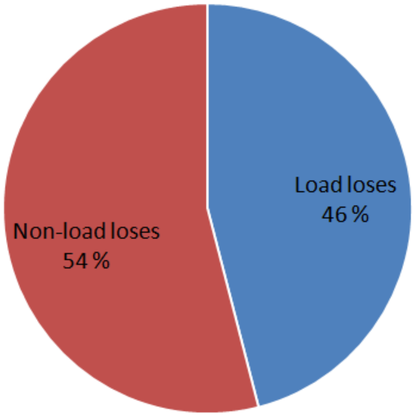

Figure 11 – Percentage of loses in load and non-load working mode [6]

The total losses consist of 54 % non-load loses and 46 % load loses. The lifespan of the transformer is estimated to 35 years.

5.3. Transformer end of the life cycle phase

Three potential end of life scenarios are possible (recycling, disposal and incineration). Most of the material is going to the recycling process then disposal and incineration. It is important to know that normally there is bigger environmental impact when intact material (new material directly from nature) is used than the material recovered through the recycling or energy recovered through incineration.

6. LIFE CYCLE IMPACT ASSESSMENT OF THE POWER TRANSFORMER

As it was mentioned earlier, SimaPRO software was used to calculate environmental impact of the transformer. The calculation is done according to the IMPACT 2002+ impact assessment method, which is as well part of the SimaPRO software. IMPACT 2002+ method calculates environmental impact in mid-point and end-point categories. Environmental impact in the mid-point categories is shown in Figure 12.

Mid-point category	Unit	Total	Production / MVA	Use / MVA	End of life / MVA
Carcinogens	kg C_2H_3Cl eq	5,37E+01	6,38E+01	4,46E+01	-5,47E+01
Non-carcinogens	kg C_2H_3Cl eq	2,05E+02	4,77E+02	1,19E+02	-3,92E+02
Respiratory inorganics	kg PM2.5 eq	1,03E+01	5,86E+00	9,13E+00	-4,71E+00
Ionizing radiation	Bq C^{-14} eq	1,60E+06	3,04E+04	1,58E+06	-1,34E+04
Ozone layer depletion	kg CFC^{-11} eq	7,69E-04	1,23E-04	6,82E-04	-3,61E-05
Respiratory organics	kg C_2H_4 eq	2,06E+00	1,74E+00	1,33E+00	-1,01E+00
Aquatic ecotoxicity	kg TEG water	1,59E+06	1,39E+06	1,05E+06	-8,49E+05
Terrestrial ecotoxicity	kg TEG soil	2,85E+05	4,12E+05	2,51E+05	-3,78E+05
Terrestrial acid/nutri	kg SO2 eq	1,37E+02	9,52E+01	1,09E+02	-6,71E+01
Land occupation	m^2org.arable	1,10E+02	1,50E+01	1,00E+02	-4,82E+00
Aquatic acidification	kg SO_2 eq	3,48E+01	3,64E+01	2,68E+01	-2,83E+01
Aquatic eutrophication	kg PO_4 P-lim	1,67E+00	1,06E+01	1,08E+00	-9,98E+00
Global warming	kg CO_2 eq	9,87E+03	3,78E+03	8,38E+03	-2,29E+03
Non-renewable energy	MJ primary	2,86E+05	5,98E+04	2,58E+05	-3,23E+04
Mineral extraction	MJ surplus	3,40E+02	5,98E+02	3,01E+02	-5,59E+02

Figure 12 –Mid-point environmental impact categories [6]

Four end-point categories exist according to the IMPACT 2002+ method, human health, ecosystem quality, climate change and resources. The environmental impact through all three phases and all four categories is given in the Figure 13.

End-point category	Unit	Total	Production / MVA	Use / MVA	End of life / MVA
Human health	DALY	8,26E-03	5,62E-03	7,19E-03	-4,55E-03
Ecosystem quality	PDF*m^2*yr	2,60E+03	3,44E+03	2,26E+03	-3,11E+03
Climate change	kg CO_2 eq	9,87E+03	3,78E+03	8,38E+03	-2,29E+03
Resources	MJ primary	2,86E+05	6,04E+04	2,59E+05	-3,28E+04

Figure 13 – End-point environmental impact categories [6]

Visual representation of the environmental impact through end-point categories is given in the Figure 14. From the figure it can be seen that the biggest environmental impact is in the human health, climate change and resource categories has use phase of the transformers life cycle. Only in the ecosystem quality category production phase has bigger environmental impact than use phase.

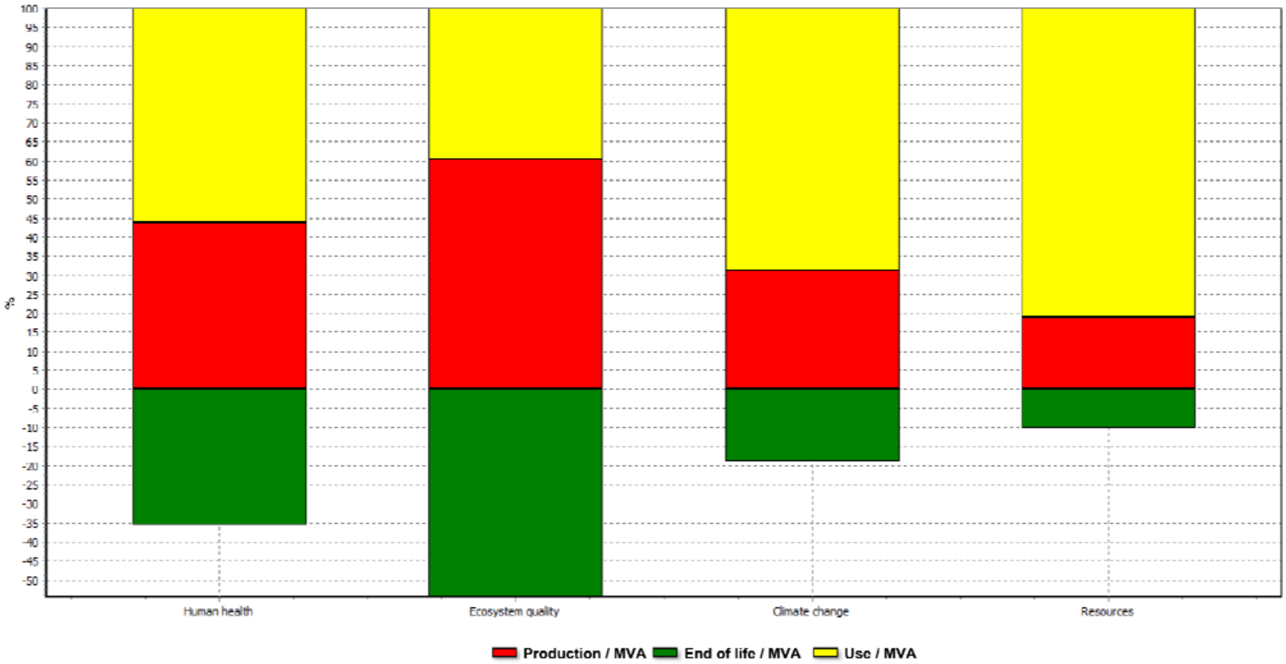

Figure 14 – Environmental impact of the power transformer [6]

6. CONCLUSIONS

The goal of this LCA was to get quantitative information about the environmental impact of the power transformer through the whole life cycle. Results of the LCA analysis will be used for the optimization of the product development process, which can be then used for green marketing purpose.

When considering results of the LCIA it can be concluded that the biggest environmental impact has the use phase. This is primarily due to the transformer losses; therefore, the environmental impact of the use phase depends on the type of energy source that is being used. The biggest environmental impact will have non-renewable sources such as a coil, oil or gas, and the least impact will have renewable sources such as hydro or biomass.

The general conclusion of the paper is that the LCA method is a very complex but generally applicable method for calculating the environmental impact of various products and processes. SimaPRO is a good tool to be used when assessing the environmental impact because of its pre-build methods and compatible Life Cycle Inventory databases such as ECLD and Ecoinvent. Experience shows that is usually difficult to obtain quality information on natural flows both downstream and upstream.

When considering CO_2 emission as key environmental indicator results show that production of the transformer contributes with only 2.9 %, transport with 1.9 %, procurement of the material and equipment 10.3 % and the biggest contributor is use phase with 84.9 %. Having this in mind, one can conclude that the biggest improvement in the environmental impact can be achieved when using renewable energy sources as well when lowering the transformer loses. Creating transformer with less transformer loses increase its price and manufacturers do not have much space to lower environmental impact simply because of the strong price competition. Accordingly, customers should take care about the environmental impact through the whole life cycle and include environmental criteria in tenders.

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